Introduction to Space Commerce

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An Economic Frontier

Do you want to look into the future? Just cast an eye skyward. One hundred miles overhead — at a distance only half as far as that between Boston and New York — is an environment of extraordinary characteristics. You're gazing at a new realm of resources.

In today's world of increasing global competition, space represents an economic frontier, a new territory of commercial opportunity. Scientific discovery and technological innovation lead to new products and services that can benefit people throughout the world, resulting in entirely new industries. Space is proving to be a fertile field for such economic growth.

Space commerce is composed of diverse activities which fall into four broad areas: satellite communications, Earth and ocean observations, materials research and processing, and space transportation and industrial services.

Satellite communications, while well established and mature, continue to develop through new applications and advancing technology. This $3 billion a year industry didn't even exist 25 years ago.

Observing our planet from space has already produced immense public benefit through improved weather forecasting and monitoring of resources and the environment. Valuable commercial applications of regular Earth observations are becoming increasingly practical through advances in computer processing and interpretation of remote sensing data from specially equipped satellites.

Space has become an industrial laboratory for materials research and

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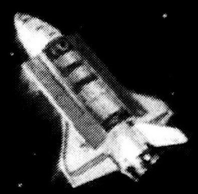

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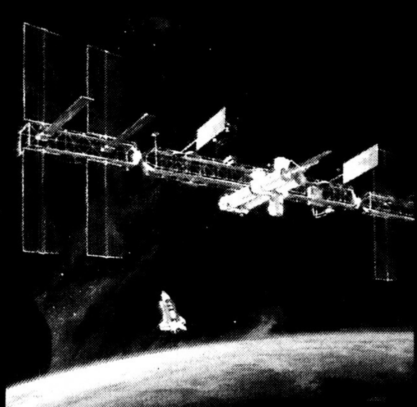


Commercial Use of Space: A New Economic Strength for America

NASA

Overleaf:

This painting by Pamela Lee shows astronaut William Fisher during a spacewalk conducted during Shuttle mission 51-I in August 1985.

processing. Today's research and development work, being carried out through government and corporate sponsorship, is expected to lead to new scientific and technological breakthroughs.

There is tantalizing evidence that unique products of high value may be processed in the weightless, high-vacuum environment of space. It is also possible that what industrial researchers learn in space could change dramatically the way materials are processed in our factories on Earth. Many believe this area offers the greatest potential for economic benefit.

These commercial uses of space, coupled with the requirements of government space programs, are prompting the emergence of a commercial space transportation industry. With broad, worldwide demand for access to space, this is the most competitive of the current commercial space activities. A variety of other industrial support services are also being commercially offered.

Business in space is not business as usual. The expansion of space commerce faces substantial challenges associated with costs, risks, and competition on Earth. But private enterprise is adapting to the environment of space, attracted by the potential returns from tapping new resources.

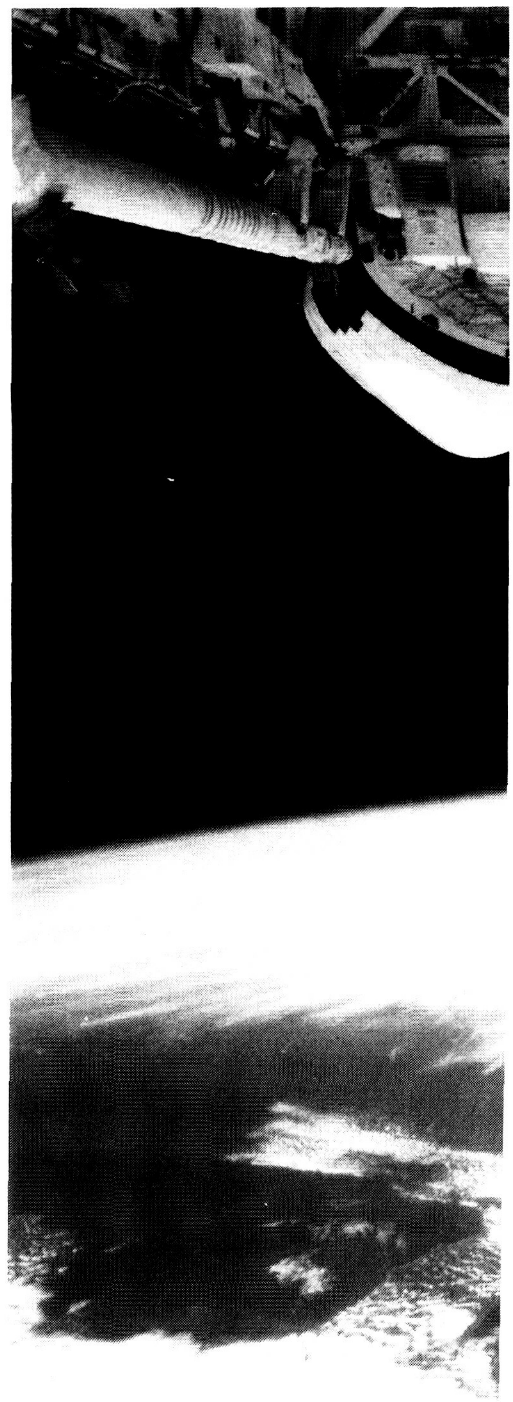
NASA's Role

The 1980s has witnessed an increasing awareness of the potential economic value of space. Amid a growing consensus that U.S. leadership in the commercial development of space is in the national economic interest, the President directed NASA in 1984 to take steps to promote commercial space activity. The Congress enacted legislation assigning NASA to "seek and encourage, to the maximum extent possible, the fullest commercial use of space."

Today, NASA is providing a focus for action to expand U.S. private sector investment and involvement in the civil space program. The agency established the Office of Commercial Programs to actively support new, high-technology space ventures, the commercial application of existing aeronautics and space technology, and commercial access to available NASA capabilities and services. This role is strengthened by NASA's rich tradition of cooperation with industry.

The roots of U.S. dedication to space leadership are contained in the National Aeronautics and Space Act of 1958. A key national objective, spelled out in NASA's charter, is "the preservation of the United States as a leader in aeronautical and space science technology and in the applications thereof to the conduct of peaceful activities within and outside the atmosphere."

NASA's effort to encourage an increasing role for the U.S. private sector in our space activities is viewed as a crucial factor in maintaining that leadership.



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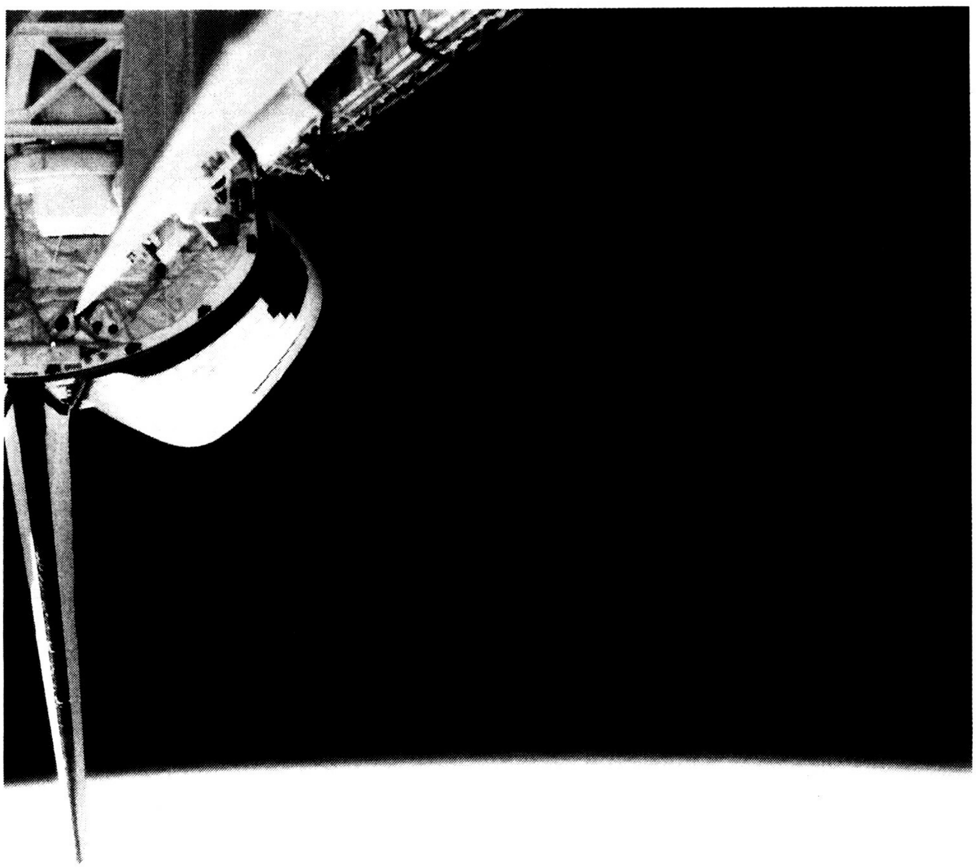
America's Space Shuttle provides a link to the new economic frontier of space, enabling NASA and U.S. industry to conduct joint research in this unique environment.

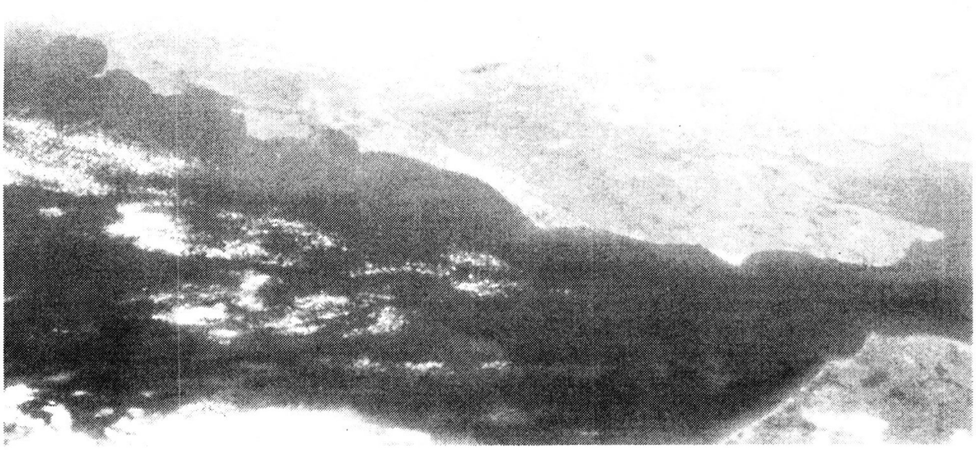


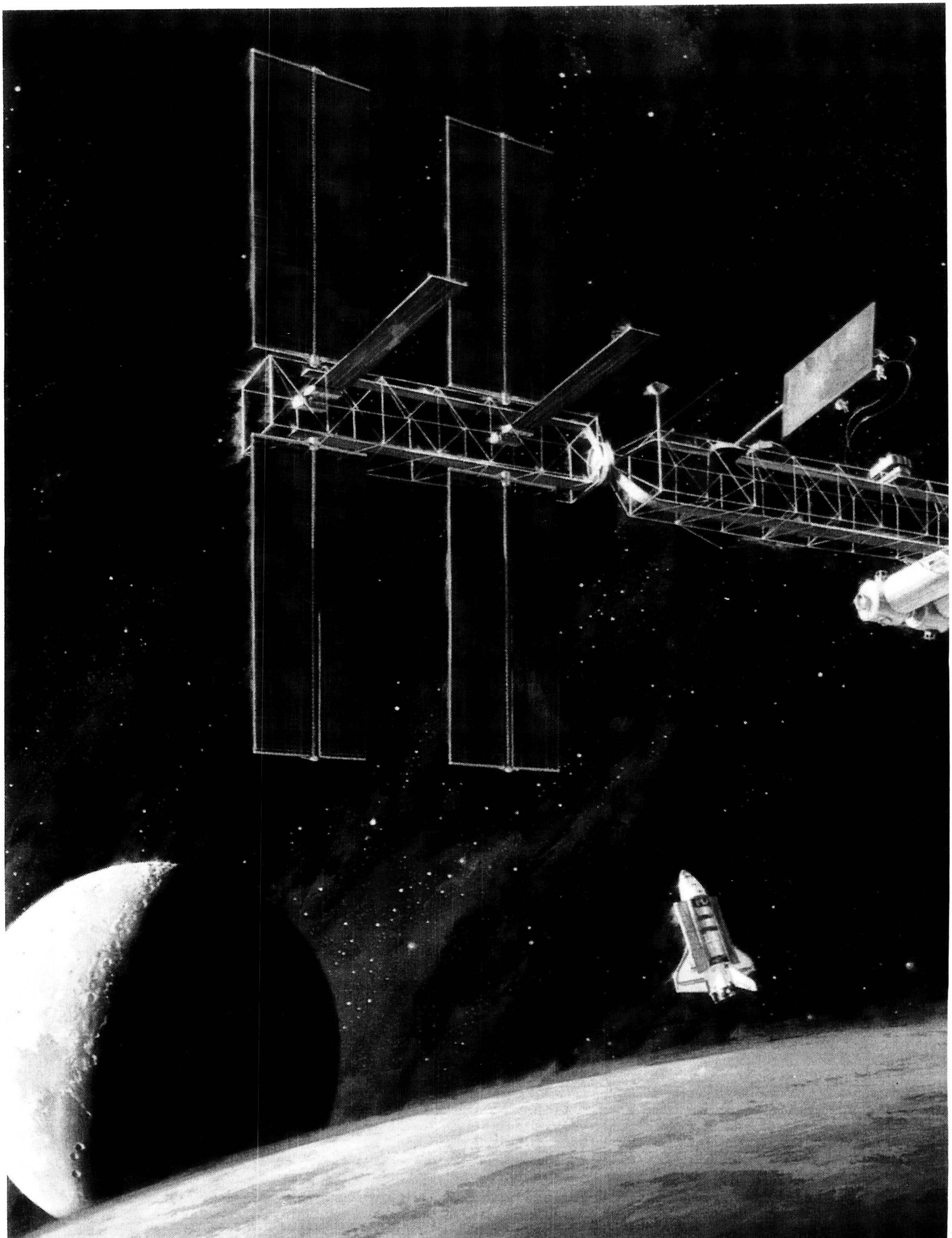
NASA's role includes:

- Leading the government's implementation of key policies aimed at reducing the financial and technical risks of doing business in space, and promoting an increasing role for the private sector in the financing and development of space infrastructure and services.

- Conducting research and development programs to expand the nation's space capabilities and explore the practical uses of space, and encouraging corporate-sponsored research and development activities to investigate the industrial applications of space.

- Supporting establishment of a U.S. commercial launch industry through the privatization of NASA-developed expendable launch vehicles, providing access to NASA launch support facilities, and use of commercial launch services.





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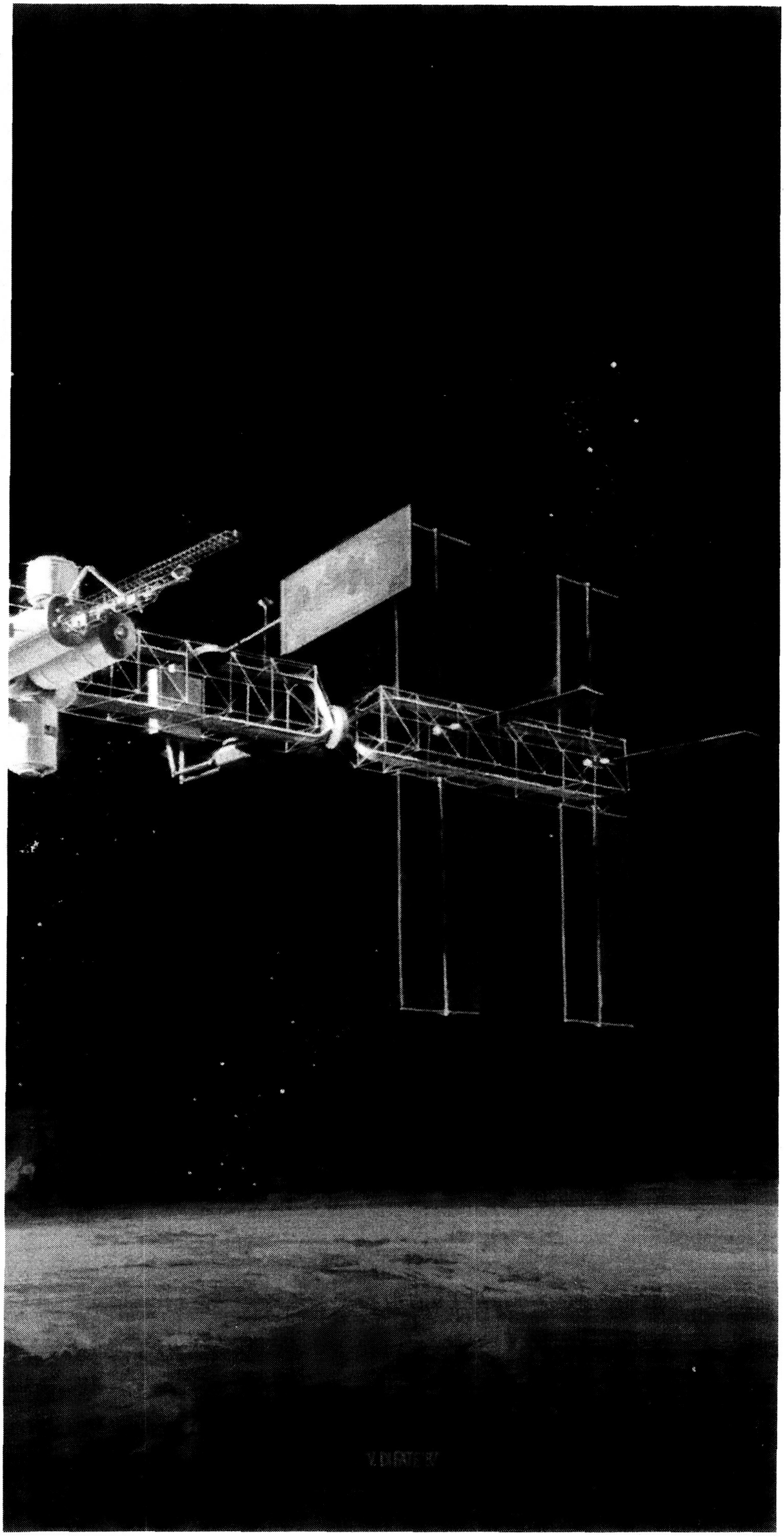

The Space Station *Freedom*, scheduled to be built in the 1990s, will be a multi-function, international complex of *modules in low-Earth* orbit.

Benefits for America

What does all this mean to America? It means an opportunity for new industries, new jobs, new products and services to benefit people on Earth; continuing leadership in civil space activities, and, a strengthened competitive position in the world economy.

The governments of all spacefaring nations are increasingly viewing space as a new arena for economic expansion. Other nations — Japan, France, Germany, and the Soviet Union among them — also recognize the alluring commercial potential of space, and are strongly challenging the United States for leadership in the industrial application of space science and technology.

A clear example of the importance of American leadership in space commerce can be found in the position of the U.S. aerospace industry, which has maintained a positive balance of trade during a period when, overall, the U.S. trade position has steeply declined.

By any measurement, the national investment in space has already produced a high-yield return in the form of technological advances and improvements in the quality of life on Earth. Through cooperative efforts with the U.S. private sector, NASA is seeking ways to increase the economic return from space, enhance our international competitiveness, and prepare this country for meeting the challenges of the 21st century.

Commercial Uses of Space

Satellite Communications

Satellite communications was the first, and is today the most mature, of the commercial uses of space. In just 25 years, this technology has produced an industry that generates $3 billion in annual revenues, created entirely new fields of employment, and transformed the very way business is conducted on Earth.

On July 10, 1962 — five months after John Glenn became the first American to orbit Earth — a 170-pound satellite called *Telstar* was rocketed into space atop a NASA Delta booster.

While much of the nation's attention toward space was riveted to the unfolding race for landing humans on the Moon, *Telstar* 1, the world's first satellite built and paid for by private industry, launched a revolution in telecommunications that marked the beginnings of space commerce.

Telstar was designed and developed by AT&T's Bell Telephone Laboratories to demonstrate the concept that an orbiting spacecraft could actively relay signals from one point on Earth to another. Within hours following the launch, Bell engineers had successfully relayed telephone and television transmissions, and soon afterward, the first "via satellite" television programming was relayed across the Atlantic.

A year later, the NASA-developed *Syncom* satellite pioneered research into use of communications satellites positioned at a distance where their orbital period is synchronized with Earth's rotation, and the spacecraft therefore remains in the same position over Earth.

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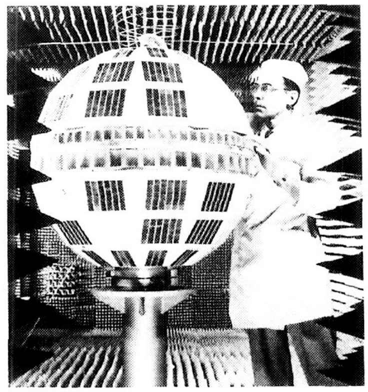
Leasat spacecraft following deployment on STS-41D



Launched July 10, 1962, *Telstar* I, the first privately financed and built communications satellite, made history with its transmission of the first live transatlantic television broadcast. Shown here is a full-scale model of the 170-pound satellite.

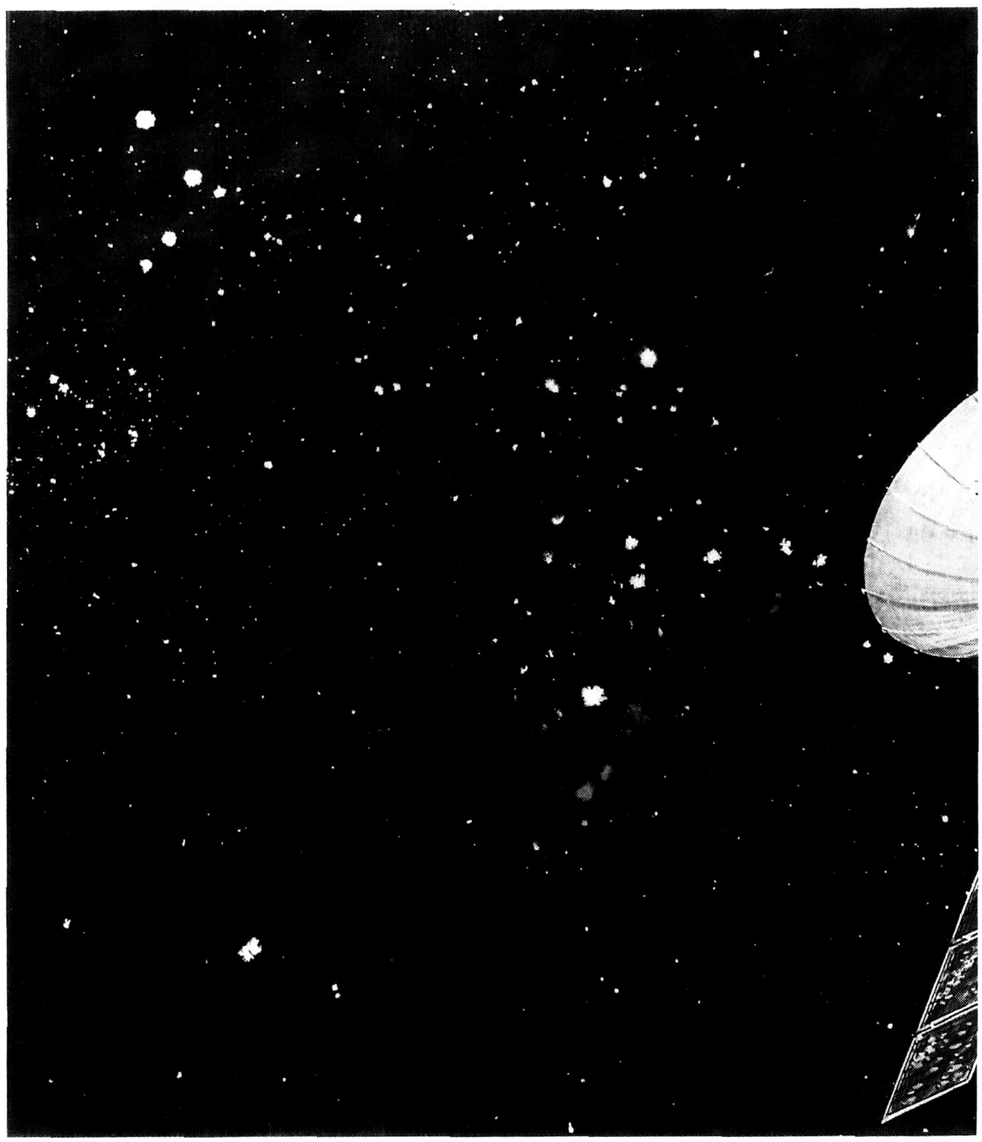
This territory of space, known as *geosynchronous orbit*, has become increasingly congested as nation after nation have joined the space age by orbiting their own communications spacecraft and international systems.

Communications satellites now carry more than two-thirds of the world's international voice communications, and transmit virtually all of the world's video programming.

Demand by communications satellite owners/operators for access to space remains strong, accounting for virtually all of the present-day private sector market for commercial launch services.

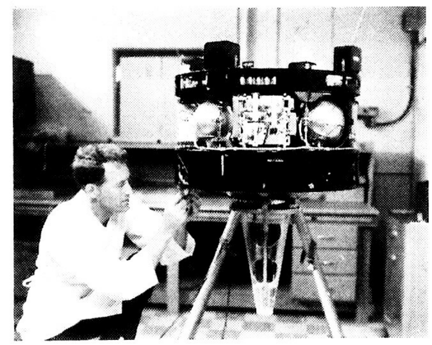
Worldwide, communications satellite billings by U.S. and foreign manufacturers totaled about $1 billion in 1987, with sales by American manufacturers accounting for approximately half the total. Projected total revenue from the sale and lease of satellite transponders in 1987 was estimated at $1 billion. Revenues to U.S. companies alone for domestic sales of ground receiving equipment totalled about $700 million in 1987.

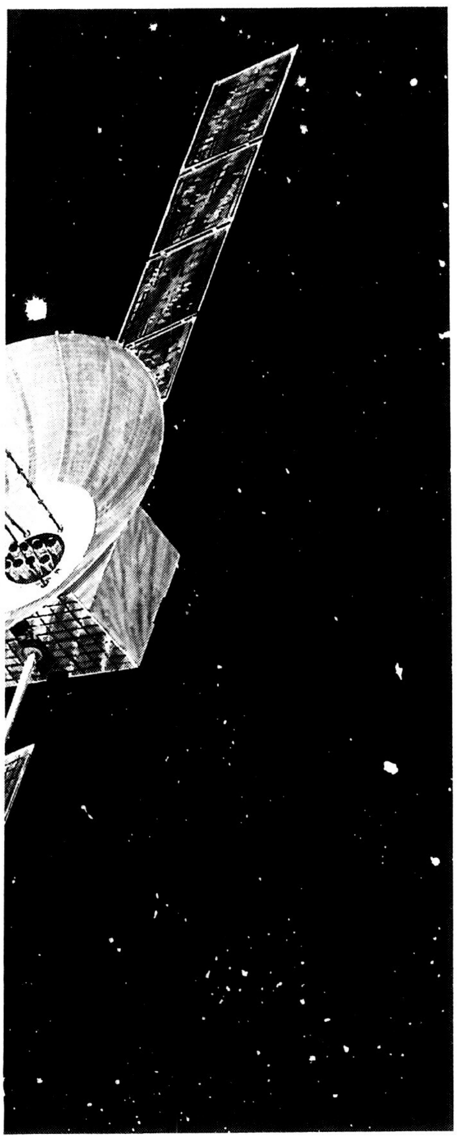
A competitive challenge to satellite communications is being posed by increasing use of fiber optic cables. This terrestrial technology challenge underscores one of the continuing risks of space commerce.



The privately owned Geostar satellite navigation system provides messaging and positioning services to commercial users worldwide.

The launches of NASA's *Syncom* I and *Syncom* II, shown here undergoing final checkout, ushered the telecommunications industry into a new era. The satellites were the first communications spacecraft to be placed in geosynchronous orbit — now the standard orbit of most of the world's satellites.



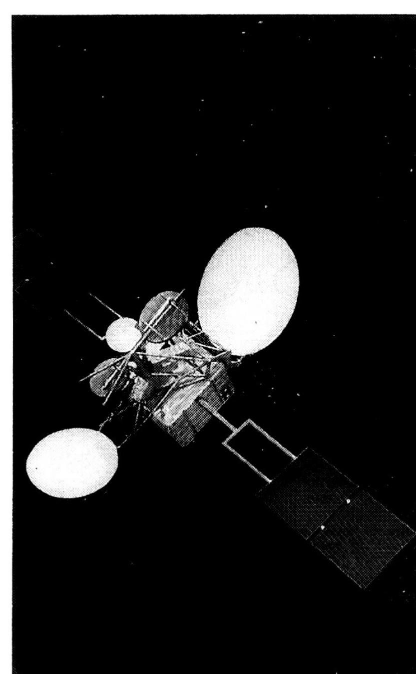


Yet new markets for communications via satellite continue to unfold. Radio determination satellite services, which among other applications will allow a central control center to track and monitor the location and status of trucks, trains, aircraft, and vessels, could become a major profit center for the satellite industry.

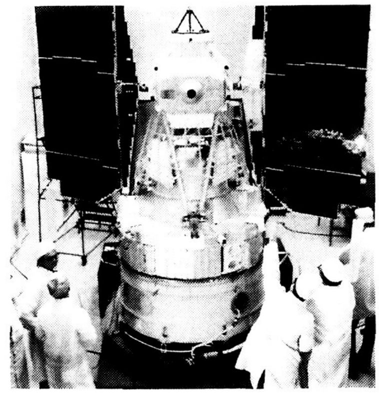
One firm already servicing this new market, Geostar Corporation, will launch satellites aboard NASA's Space Shuttle under a Space Systems Development Agreement — which allows a deferred payback of standard launch service costs.

Research and development work to advance satellite communications is continuing both here and abroad. NASA, for example, is working to develop the Advanced Communications Technology Satellite (ACTS). A key issue of this relatively mature industry is how to properly continue to advance the technology.

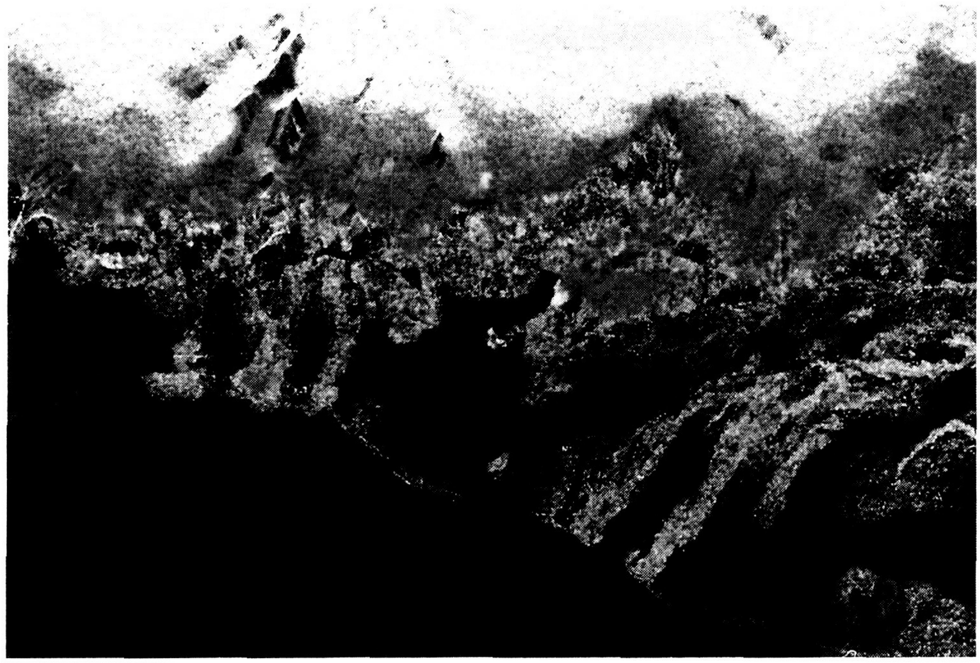
NASA's Office of Commercial Programs is considering the possible establishment of a Center for Commercial Development of Space, funded through contributions by both government and industry, focused in this area.



This artist's concept depicts NASA's Advanced Communications Technology Satellite — a development program designed to demonstrate new technologies in areas ranging from antennas to processing.



Earth and Ocean Observations



Commercial Earth and ocean observation from space is an emerging area of space commerce that is being assisted by privatization policies and the growth of a "value added" industry based on the interpretation and analysis of satellite gathered data.

Remote sensing observations, based on space-based or airborne measurements of reflected or emitted electromagnetic radiation, can reveal features and characteristics of Earth's land and ocean surface that are difficult or impossible to detect in ordinary photographs.

Advanced optical instruments and radar sensors collect data in digital form, sending it back to Earth receiving stations. Computer processing and enhancement of the images can make the invisible visible.

Since the beginning of the space age, it has been realized that the unique vantage point of Earth orbit provides an unparalleled perspective of our planet. Our earliest application of this resource was the use of meteorological satellites to provide a global picture of weather patterns, resulting in vastly improved weather forecasts.

In 1972, NASA launched the first Earth Resources Technology Satellite (ERTS-A) to demonstrate the usefulness of remote sensing on a global and repetitive basis. Specifically, the ERTS mission was to determine what data could be gathered by an unmanned spacecraft, how this data could be interpreted and applied to a broad range of endeavors, and how the information yield could be of economic or social value to commercial, scientific, and government interests.

The spacecraft subsequently was renamed *Landsat* 1 and became the first of five *Landsat* spacecraft orbited to date. The system was declared operational in 1983 and transferred to the National Oceanic and Atmospheric Administration as part of a privatization program.

NASA's research and development programs demonstrated that remote observations from space can assist a wide diversity of Earth-based activities, such as exploring for oil and minerals, forecasting crop yields, managing forest resources, monitoring the environment, and documenting land uses.

Today, the system is operated by the Earth Observation Satellite Corporation (EOSAT), which markets *Landsat* data to end-user customers and other commercial ventures which add value to the *Landsat* images by computer processing and interpretation tailored to be useful to specific groups of customers.

This still young area of commercial space activity has already attracted international competition.

In 1986, France entered the commercial Earth observation market by launching its *Systeme Probatoire d'Observation de la Terre* (SPOT) satellite and creating a commercial entity to market the satellite data worldwide. The Soviet Union has started marketing photographic images from its remote sensing satellites as well as photographs taken from the *Mir* space station. Japan and India have also launched remote sensing spacecraft, and other nations have announced plans to do so.

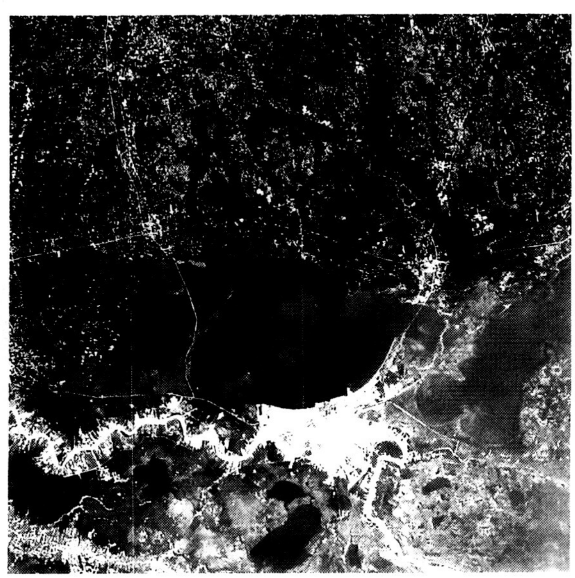
NASA is helping to stimulate and expand the commercial application of remote sensing technologies through

The first Earth Resources Technology Satellite, later renamed *Landsat* 1, is seen here prior to its launch in 1972 as part of an experimental program to explore the use of satellite images to measure properties of Earth's land, ocean surface, and atmosphere from space.

This image of forests in northeastern Florida was acquired during Shuttle mission 41-G using Shuttle Imaging Radar-B.

sponsorship of research projects. The Stennis Space Center in Mississippi — designated as the lead NASA center for commercial Earth and ocean observations — is managing contracted research studies. Two of the agency's 16 Centers for Commercial Development of Space were established to advance commercial participation in and use of Earth and ocean observations.

NASA is also continuing to advance Earth observation technology, through new systems like the Shuttle Imaging Radar (SIR).



This *Landsat* 4 image shows the gulf coast of southern Louisiana and Mississippi.

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Materials Research and Processing

Still in its infancy, the commercial use of space for materials research and processing is a field of interest to industrial scientists and engineers worldwide.

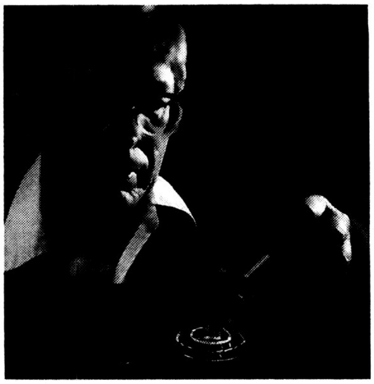
In the extraordinary environment of space, experiments are being conducted today that will lay the foundation for future space-based production of high-value products. Aboard orbiting laboratories, objects float in a weightless state as the familiar influences of gravity become almost totally absent. In addition, space offers a limitless, nearly perfect vacuum.

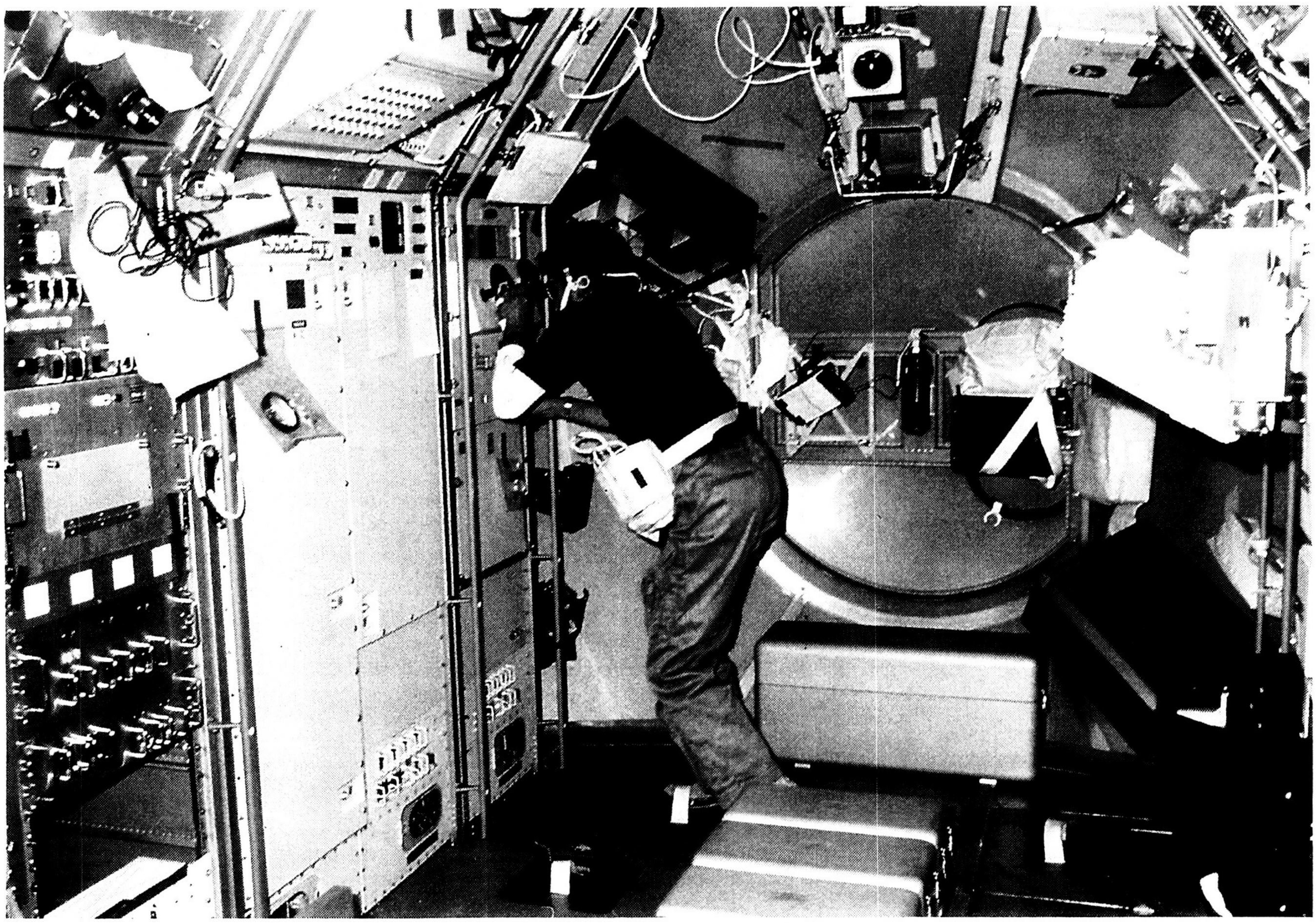
To many people on Earth, the most novel aspect of spaceflight may be the sight of astronauts turning effortless somersaults without ever touching the surfaces of their spacecraft. But scientists interested in the behavior of materials tend to be fascinated with other curiosities of this microgravity environment. What they are learning could change our lives on Earth.

The opportunity to conduct industrial research in an environment where conditions are so different from those on Earth could result in dramatic advances in our knowledge of materials and processes, leading to new methods of production in Earth-based factories. We may also learn that certain space processed materials may be sufficiently superior to their Earth counterparts to economically justify space manufacturing. And still other, yet-to-be discovered products may be entirely unique to space and unattainable on Earth.

Dr. Lodewijk van den Berg (top, opposite page), an EG&G scientist who flew as a payload specialist aboard the Spacelab 3 mission in 1985, views a space produced crystal of mercuric iodide. The crystal was grown in a special furnace (left) carried in the Spacelab pressurized module, and was later determined based on ground tests to be superior in quality to similar crystals grown in Earth laboratories. Van den Berg is seen observing the progress of the experiment during the flight (bottom opposite page).

Already, aboard the Space Shuttle and other spacecraft, special processing equipment has been used to demonstrate that crystals of materials that serve as key components of electronic and optical devices can be grown larger, and more perfect in the microgravity of space. It may become economically feasible to manufacture





such crystals in space, leading to improved semiconductor chips that enable us to build faster computers.

A number of U.S. firms, working in cooperation with NASA, plan to test equipment and processes to produce semiconductor materials in space aboard the Shuttle.

Pharmaceutical companies are keenly interested in the prospects for producing protein crystals of superior quality in space. If the space environment does permit the growth of more perfect protein crystals, the result could be advances in the development of new life-saving drugs. McDonnell Douglas has already demonstrated the value of space as a pharmaceutical processing site. On seven Space Shuttle flights, the company flew its electrophoresis system, which separates biological materials far more efficiently than is possible on Earth. Work was progressing towards scaling up the process to commercial in-space production until the *Challenger* accident grounded Shuttle flights, forcing the company to put its plans on hold.

Still other possibilities lie in the processing of unique glasses, new metal alloys, and composites. Over 400 exceptionally strong and light metal alloys have been identified as potential candidates for space manufacture.

Government-sponsored materials science research in microgravity dates back to the early years of the space program. Early materials processing experiments were conducted aboard sounding rockets and in ground-based drop towers. America's Skylab orbital workshop enabled the first long-duration opportunities for materials research in space.

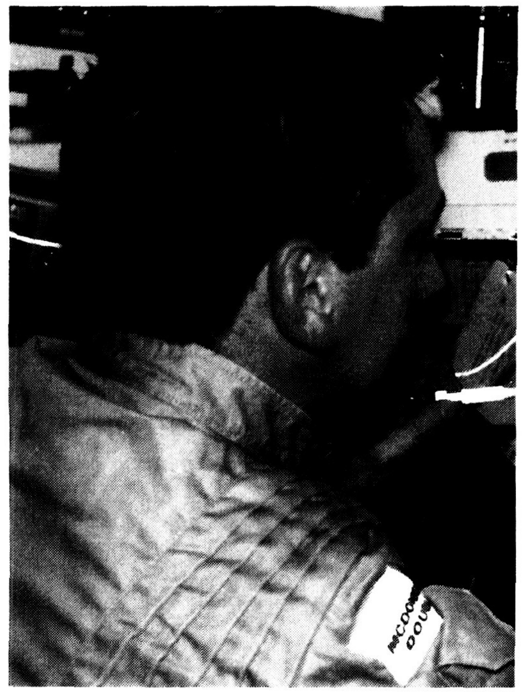
As in other areas of commercial space use, the interest in materials research and processing by our spacefaring trading partners and other nations is strong and growing. The European Space Agency, which financed and built the Shuttle-based Spacelab orbital laboratory, has an established microgravity materials processing program. Active national programs are being conducted by the Federal Republic of Germany, France, and Japan.

The Soviet Union has reportedly produced some 2,000 pounds of space manufactured crystals aboard its orbiting space stations.

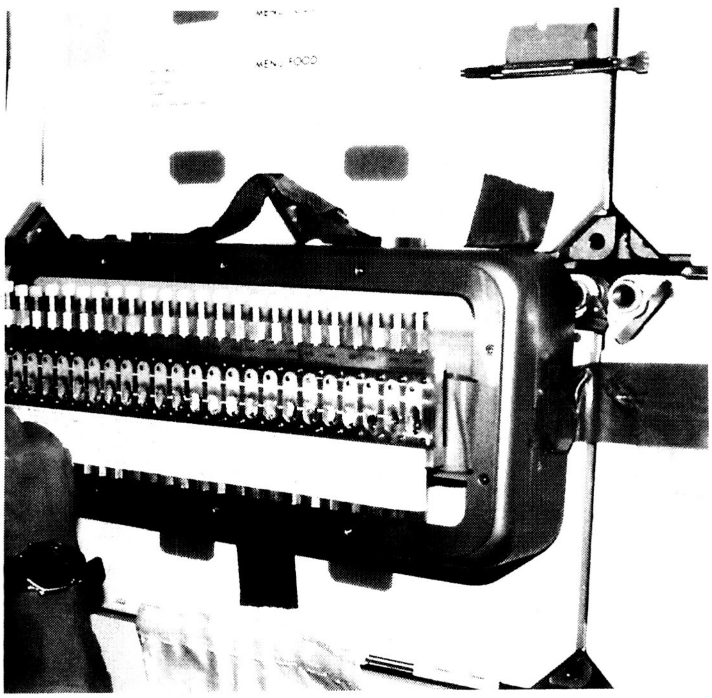
The first commercial made-in-space product offered for sale was developed by Lehigh University working in cooperation with NASA. Using the Monodisperse Latex reactor aboard the Space Shuttle, perfectly matched spheres of latex were manufactured for use in calibrating precision instruments such as electron microscopes. Small vials, each containing millions of the latex spheres, are available for purchase through the Commerce Department's National Bureau of Standards as a standard reference material.

It's impossible to predict when additional commercial products from space may become available. But an expanding list of companies are actively laying the groundwork by conducting investigations in ground-based laboratories, aboard specially equipped aircraft and sounding rockets that provide brief periods of microgravity, and in space itself.

While the interruption of Space Shuttle flights resulted in a delay of flight opportunities for industrial research and development in space,



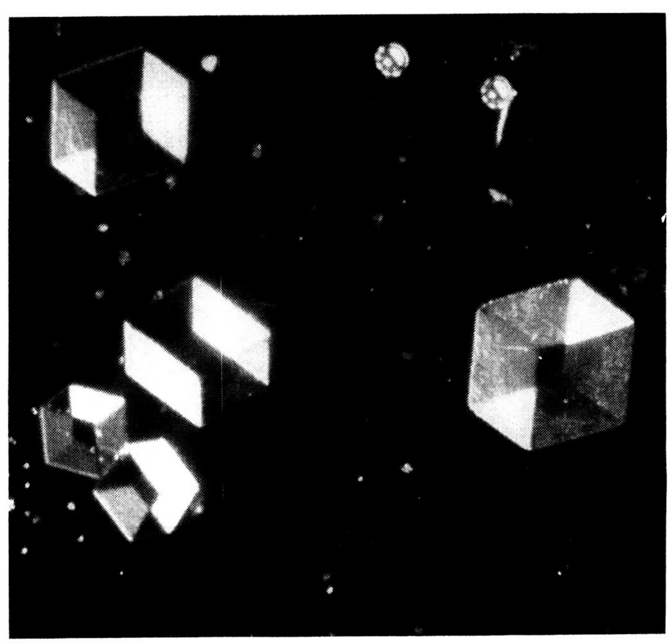
Charles Walker, the first corporate astronaut, is shown working on a protein crystal growth experiment during Shuttle mission 61-B. Walker flew on several Space Shuttle missions conducting experiments related to McDonnell Douglas' biological materials separation process.



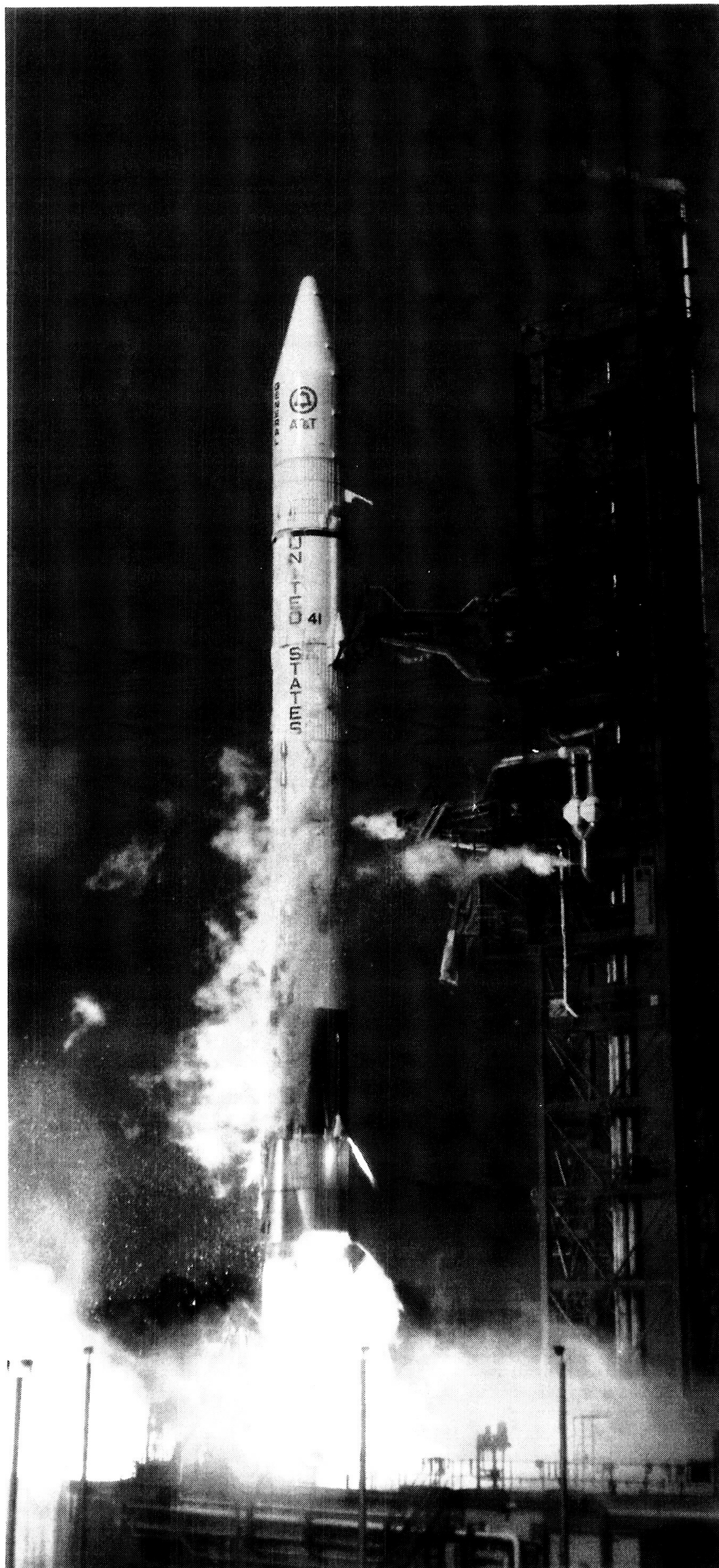
commercial interest in the field has continued to grow. Aboard *Discovery* when the Space Shuttle resumed flight were experiments by 3M and industrial researchers representing DuPont, Merck, Schering-Plough, Upjohn, and Burroughs Wellcome.

As the materials processing science and technology base builds, the long-range outlook appears promising for commercial uses of the unique characteristics of space. Many believe this area of commercial application, though it still faces many challenges and will require years of development, can be expected to provide substantial future contributions to economic growth through the emergence of new products and services.

Protein Crystal Growth experiments aboard the Space Shuttle — representing cooperative efforts of NASA, industry, and universities — may lead to the creation of powerful new drugs. Pictured here are Concanavalin B crystals grown on Shuttle mission 61-C.



The Atlas-Centaur, built by General Dynamics, was developed by NASA as a workhorse of the space program. It is now one of several boosters in the vanguard of a new U.S. commercial launch industry.



Space Transportation and Industrial Services

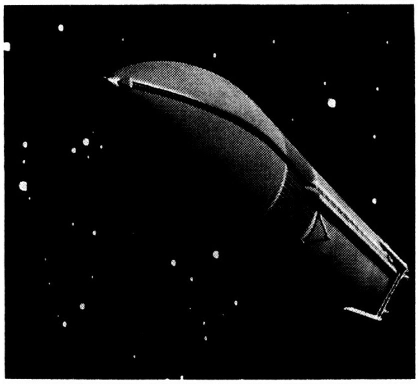
Increasingly, private companies are becoming the providers of space transportation and other services that a few years ago were available only from the government.

Companies that once built rockets under contract to NASA and the Air Force are now developing private launch vehicles and offering commercial services to satellite owners. New entrepreneurial firms are joining them, seeking untapped niches in the worldwide demand for access to space.

The demand of transportation services to launch commercial communications satellites has sparked fierce competition. Even before the Space Shuttle *Challenger* accident, NASA's Shuttle was under a strong challenge by Europe's unmanned *Ariane* booster. The Soviet Union and China are both marketing their launch vehicles to western users.

Today, as a result of post-*Challenger* policy decisions, the Space Shuttle no longer competes for communications satellite payloads that can be flown on unmanned rockets. NASA and other federal agencies are actively promoting and supporting the establishment of a U.S. expendable launch vehicle industry.

While the *Ariane* has captured a major market share for commercial satellites waiting in line for launch opportunities, the U.S. firms McDonnell Douglas, General Dynamics, and Martin Marietta are showing gains through new contract signings. Contracts with these American companies to launch satellites for foreign and international organizations between 1989 and 1992



NASA is working with private industry to explore possible commercial uses of Space Shuttle external tanks, which are currently discarded after each launch.

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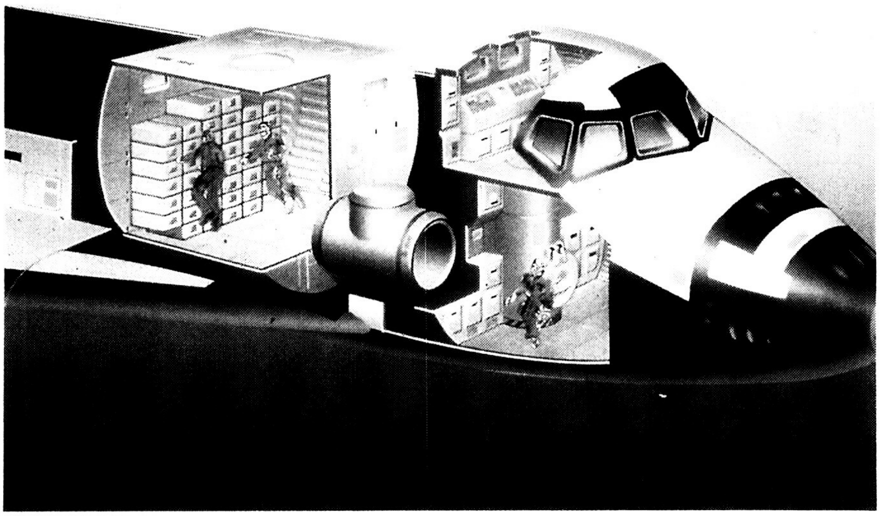
An artist's concept of SPACEHAB, Inc.'s pressurized module, which will augment capabilities of the Space Shuttle. Under an agreement with NASA, the modules will be flown aboard the Shuttle beginning in 1991 and operate as a commercial venture.



presently amount to approximately $600 million. NASA and other U.S. government agencies are also providing business to the domestic launch industry through contracts for commercial launch services.

Aggressive marketing of launch services by the Soviet Union and China pose an additional challenge, and the overall issue of free and fair trade is a major concern to U.S. launch service providers.

Beyond commercial launch services, some companies have privately developed and marketed upper stages — the small rockets that transport satellites from a temporary low orbit to their permanent orbital stations. McDonnell Douglas developed the Payload Assist Module (PAM) and Orbital Sciences Corporation developed the Transfer Orbit Stage (TOS).

Another commercial entry into industrial support services is Astrotech Space Operations Limited Partnership, which has established a private processing facility near Kennedy Space Center for the pre-launch preparation of satellites and other payloads.

In addition, industrial research into the practical uses of the space environment, and anticipated commercial operations emerging from the discovery of economically viable applications, are prompting the development of privately financed and developed space facilities.

Washington-based SPACEHAB Inc., for example, is privately developing modules that will expand the capability of the U.S. Space Shuttle by increasing the amount of pressurized volume available for orbital research and commercial activities.

Under an agreement with NASA, SPACEHAB will fly its modules aboard the Shuttle beginning in 1991. SPACEHAB will commercially market space in the module and reimburse NASA for standard launch service costs after each mission.

Other concepts for commercially developed orbital facilities include the Industrial Space Facility (ISF), a free-flying orbiting facility that could house both research and commercial processing activities, and the possible use of discarded external tanks.

Increased commercial participation in the provision of space infrastructure and services is being encouraged by the government to expand the range of capabilities available to both government and commercial users.

Commercial providers have been invited by NASA to explore potential contributions to the facilities and services which will comprise the Space Station *Freedom* — the multipurpose, international complex of orbiting modules and support systems scheduled to be placed in orbit in the 1990s.

NASA's Commercial Development Program

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A Partnership with Industry

Through a family of cooperative agreements with private ventures, and a policy that encourages and assists industrial researchers in using NASA's capabilities, the agency has expanded its partnership with U.S. industry.

Today, more than half of the 50 largest U.S. industrial corporations have become participants in one or more of NASA's programs to encourage increased commercial involvement in America's civil space program. These include cooperative efforts such as Joint Endeavor Agreements (JEA) — a no-exchange-of-funds arrangement where NASA sponsors spaceflight opportunities for companies which commit corporate resources to build and conduct industrial experiments.

3M is one of several firms that have an active Joint Endeavor Agreement with NASA. The company has already flown experiments in crystal growth and organic thin films aboard the Space Shuttle and has applied for a number of patents related to their space research activity.

Other JEA partners plan to investigate the commercial potential of processing semiconductor materials in space. Unocal (Union Oil of California) has initiated discussions with NASA concerning a possible joint endeavor to support the private development of remote sensing technology for use in seeking out energy resources.

Another NASA agreement, the Space Systems Development Agreement (SSDA), is helping companies like Geostar Corporation and SPACEHAB to get off the ground by offering


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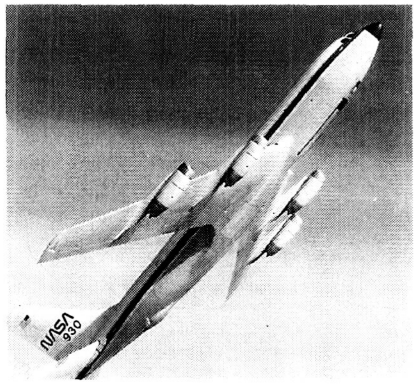
Space Station *Freedom*



By flying a series of *parabolic trajectories*, the specially equipped NASA KC-135 aircraft can achieve repeated 20-to 30-second periods of microgravity.

In the Shuttle's middeck, NASA *astronaut* James D. Van Hoften operates 3M's industrial experiment in organic thin films.

launch services on a deferred payback arrangement.

And NASA assistance and cooperation has been crucial to the startup of the fledgling U.S. commercial launch industry. This includes NASA agreements to privatize the production of government-developed launch vehicles, provide access to government launch and support facilities, and use commercial launch services.

With NASA's help, a growing number of companies are taking an initial step into space without ever leaving the confines of Earth. Industrial experiments in specially equipped NASA aircraft and ground facilities can provide "snapshot" insights into microgravity processes and enable commercial investigations of remote sensing.

The KC 135 aircraft, the same plane in which NASA astronauts get a taste of what they will experience in the microgravity of space, affords industrial scientists and engineers opportunities to verify the operation of equipment, and even produce materials samples in weightlessness.

Other NASA facilities, like the Microgravity Materials Processing Lab at Lewis Research Center in Cleveland, Ohio, also provide access to ground-based microgravity research.

The Earth Resources Laboratory at NASA's Stennis Space Center, near Bay St. Louis, Mississippi, operates research aircraft that support investigations of commercial remote sensing, such as those being carried out by Unocal.

Centers for Commercial Development

The establishment by NASA of 16 Centers for the Commercial Development of Space (CCDS) is among the most important steps taken to date to encourage greater involvement by the U.S. private sector in space.

A number of the top Fortune 500 industrial firms and scores of small businesses have become affiliated with these innovative research and development centers, which combine the support of government with the talent of American universities and the commercial interest and investment of U.S. industry.

Through one of these centers, the Center for Macromolecular Crystallography at the University of Alabama-Birmingham, a group of pharmaceutical companies are investigating the potential of space-grown protein crystals to support new drug research. The industrial participants in protein crystal growth have been able to fly samples of interest to them on several Space Shuttle flights.

The corporate participants at other CCDS centers are also expected to gain access to spaceflight opportunities through a new agreement mechanism known as a Pre-Joint Endeavor Agreement.

Ongoing research at the centers includes work on advanced materials, space remote sensing, space processing, automation and robotics, space propulsion, bioscience, and space power.

In late 1986, researchers associated with two of NASA's CCDS centers announced a breakthrough in superconductivity. In conjunction with research on the use of the vacuum of space for producing semiconductor materials, Dr. Paul Chu, of the University of Houston CCDS, and Dr. Mau Wu, of the University of Huntsville-Alabama CCDS, successfully raised the temperature at which material becomes superconductive. Another advance was reported by Dr. Chu in early 1988.

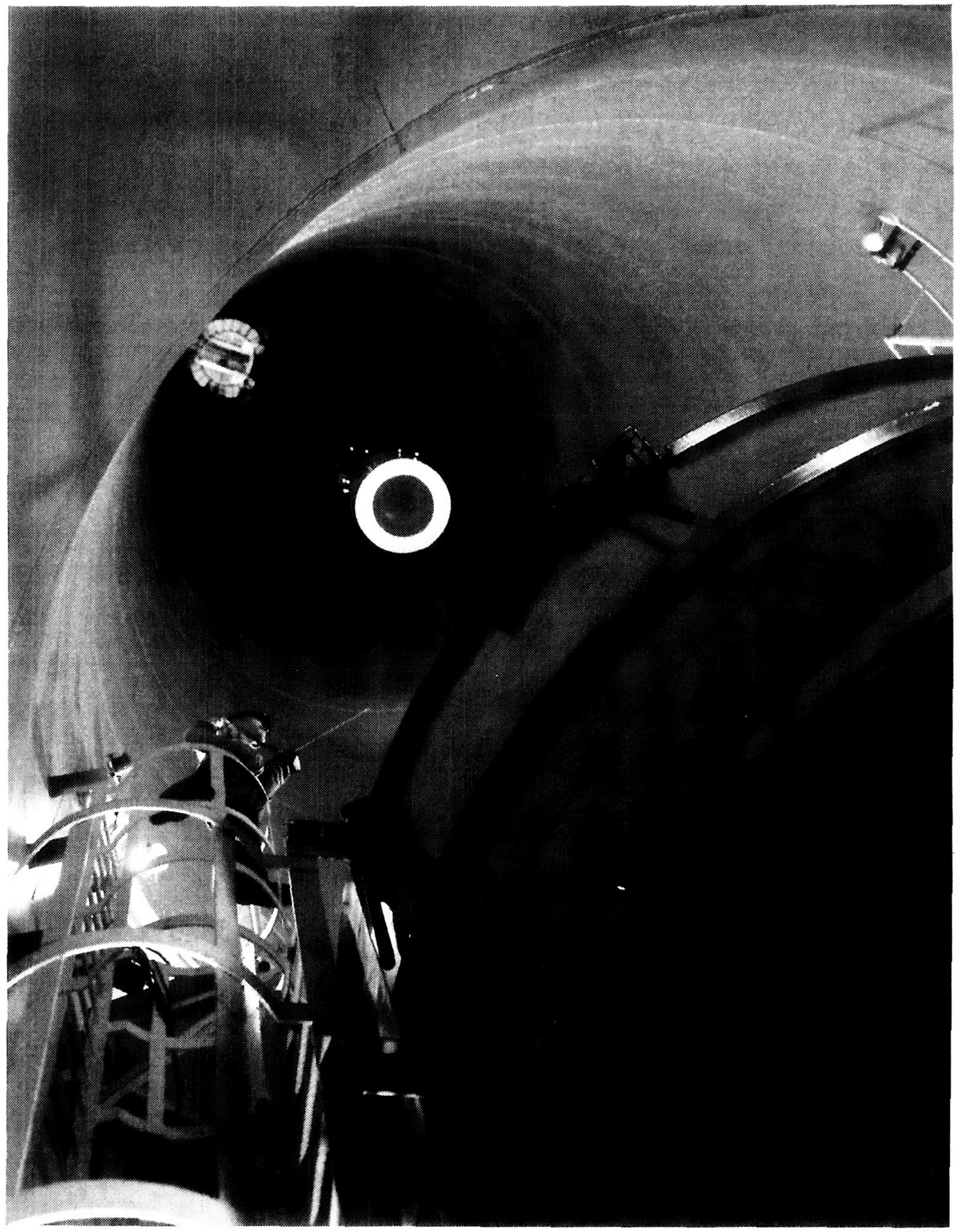
NASA provides annual funding of up to about $1 million for each CCDS, which receives additional financial and in-kind contributions from industrial affiliates that on the average exceed the level of NASA funding. NASA support for the centers is expected to continue until they can become fully established and self-sufficient.

Centers focusing on materials research and processing include the Center for Advanced Materials, Battelle Columbus Laboratories, Columbus, Ohio; the Consortium for Materials Development in Space, University of Alabama-Huntsville; the Center for Macromolecular Crystallography, University of Alabama-Birmingham; Center for Space Processing of Engineering Materials, Vanderbuilt University, Nashville, Tennessee; Space Vacuum Epitaxy Center, University of Houston, Houston, Texas; and the Center for Development of Commercial Crystal Growth in Space, Clarkson University, Potsdam, New York.

Specializing in commercial remote sensing applications are the Institute for Technology Development Remote Sensing Center, Stennis Space Center, Mississippi; and the Center for Mapping, Ohio State University, Columbus, Ohio.

Two centers — the Space Power Institute at Auburn University, Auburn, Alabama; and the Center for Space Power, Texas A&M University, College Station, Texas — focus on the commercial development of space power systems. Two others — the Center for Bioserve Space Technologies, University of Colorado, Boulder; and the Center for Cell Research, Pennsylvania State University, University Park, Pennsylvania — are working in the area of bioscience.

The remaining CCDS centers are the Wisconsin Center for Space Automation and Robotics, University of Wisconsin, Madison; the Center for Autonomous & Man-Controlled Robotic and Sensing Systems, Environmental Research Institute of Michigan, Ann Arbor, Michigan; the Center for Materials for Space Structures, Case Western Reserve University, Cleveland, Ohio; and the Center for Advanced Space Propulsion, University of Tennessee Space Institute, Tullahoma, Tennessee.



NASA Research and Development

The United States has for some 30 years been a leader among space-faring nations in conducting space research and in applying the results to practical use.

If the U.S. is to occupy this position in the years ahead, a strong national space research and development program must be maintained.

Technical capabilities and scientific knowledge gained through NASA research and development has formed the foundation for both current and projected commercial uses of space.

NASA continues to conduct and support research in advanced communications technology, remote sensing technology and applications, and materials research and processing in microgravity. The agency also carries out continuing programs to expand the nation's technical capabilities to access and operate in space.

Today, the National Space Transportation System — NASA's name for the Space Shuttle and all of its associated ground and flight components — serves as an invaluable national asset for the exploration of space. By supporting the conduct of NASA's science investigations, and industry's basic and applied research, the Shuttle is also a key to the development of space resources.

The Space Station *Freedom* will provide a permanent beachhead on the economic frontier of space. In this international collection of research modules, where astronauts will live and work for months at a time, scientists will further advance their knowledge of the unique environment of space.

This orbiting station will become the support infrastructure that makes a growing diversity of commercial activity in space possible. Private firms are expected to participate in the provision of station-based facilities and services. Commercially developed facilities for industrial research and production may become part of the station complex, or exist as free-flying units which use station support services as required.

In years past, new methods of transportation played a key role in expanding our economy. America's wilderness frontiers were opened by the railroad. International commerce was revolutionized by the airplane. And in the 21st century, a robust and expanding space economy will be the legacy of our pioneering efforts to venture outward from Earth.

The United States is today uniquely capable of leading the exploration and development of space. Through continuing NASA research and development, and cooperative efforts with U.S. industry, the commercial use of space will expand, offering hope for new economic strength from America's space enterprise.

A drop tower at NASA's Lewis Research Center offers several seconds of microgravity as samples free fall. These and similar NASA facilities provide industrial scientists a valuable Earth-based resource for investigating commercial applications of the space environment.

Industrial research and development will comprise a substantial share of the U.S. Microgravity Laboratory 1 (USML-1) Spacelab mission, planned for launch in 1992. The Spacelab pressurized module is shown here being prepared at Kennedy Space Center for a flight.